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Green Inventory Model for Battery Waste Management

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Abstract

The manufacturing sector drives countries towards economic growth with the largest contributor to the waste generation index. Waste management is a daunting task in these manufacturing sectors, and stringent environmental sustainability laws have made it mandatory. Producing high quality products that meet the needs of consumers is the expected result of the production process, and tries to reduce the generation of waste. One of the emerging types of pollution was caused by the generation of e-waste in the environment without treatment. In recent times, advances in technology have made modern machinery in factories and electronic conversion of all mechanical processes has lightened production tasks but it increases electronic waste. In this paper, an inventory model is proposed with the inclusion of a battery waste management cost estimate. Battery waste management is to minimize environmental impacts and maximize re-use, recovery and recycling process. The proposed model will certainly meet the needs of decision-makers in the field of environmental sustainability and economic development.

Keywords: Inventory model, battery waste, recycling, disposal, resource circulation and environmental product taxation.

1. Introduction:

The manufacturing sectors are still bound by the classical constraints of profit maximization and cost minimization, but recently, their incompetence in combating waste generation has led to tied up in the shackles of waste management. Nowadays the manufacturers attempt to solve pollutant emissions, waste discharge and other disposal crises. Besides environmental challenges, industries are also facing issues related to battery waste management, which is a growing environmental problem of industries.

Deposit refund system can be employed to ensure high rates of recovery of certain specific products, where the mechanism of charging deposits and paying refunds can be operated at an acceptable cost relative to the gains from achieving high rates of return of the products concerned. The purpose of deposit refund system is to prevent mixing hazardous waste such as batteries and consumer electronics into general household waste which it would be very expensive to dispose and also affects the public health. The refund for returned product is an incentive to ensure a high rate of compliance to disposal the waste in proper manner. Deposit refund system can be used very effectively to ensure high recovery rates for certain types of packaging and end-of-life products: (i) End-of-life products or packages are collected for reuse or recycling; (ii) Products or materials that would be dangerous or too expensive if thrown into the general waste stream, should be disposed of safely by a professional collector (eg. batteries); and (iii) Products containing valuable materials for reuse or recovery. Separate collection of batteries has been a priority in waste management policy, due to the potential harm of placing batteries in landfills or incineration waste streams. The mechanism involved in DRS is usually simple. For example, when selling batteries, the seller will receive a deposit and then return it when the used battery is returned to an approved collection point. Large amounts of returned products can be obtained for reuse or recycling because returns encourage consumers to return products through appropriate channels rather than disposing of them with general waste.

The mechanism of battery waste management involves several stages. First, the manufacturing company collects gathered batteries from disposal points. The next step is to disassemble the battery into fragments and to recover electrolyte. Separate the plastics and paper components from the lead and cathode, anode and metals components and discard the carbon black. Finally, Cathode, anode and heavy metals are move for the final recycling process.

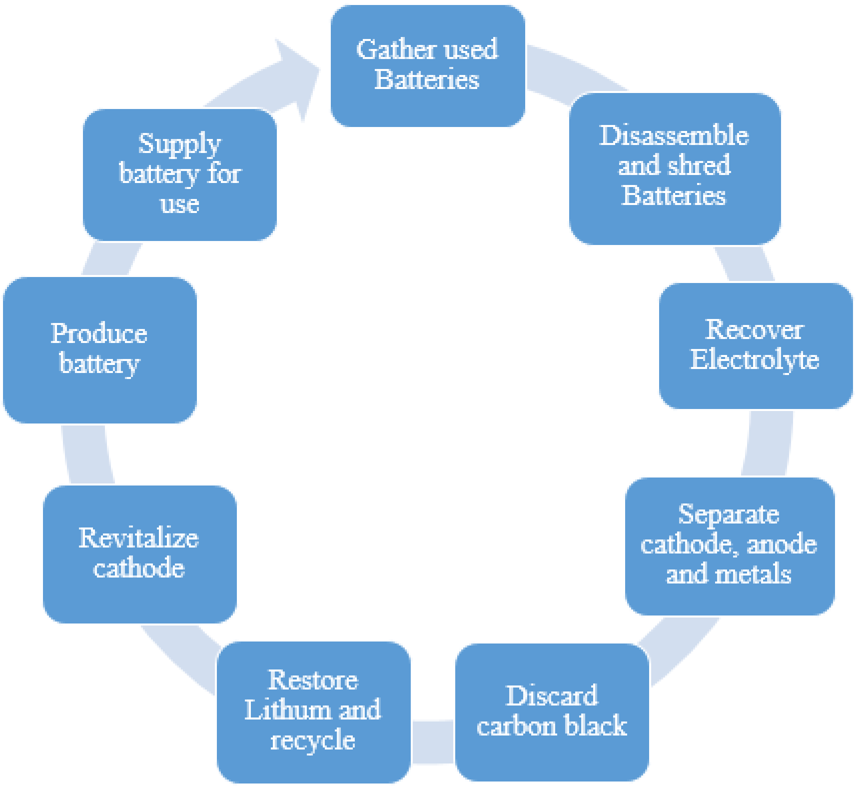

Figure 1: Battery Recycle Mechanism

Resource circulation costs are defined as the costs incurred to have a sustainable flow of costs. Resource circulation efforts include waste minimization, cyclical use of usable resources regardless of market value (reuse, recycling), and proper disposal of waste which are not recycled. Environmental taxation on products is to promote the production and use of greener products and direct economic activity in a direction that causes less damage to the environment. Environmental taxes on products have two main potential channels of influence: (i) If higher taxes on dirty products result in higher prices for these products compared to less taxed green products, this will tend to change consumer choices, leading to a direct switch to greener products. (ii) Manufacturers could also be encouraged to produce or develop cleaner products as they would have to pay less taxes. Both environmentally related product taxes such as VAT and excise taxes can be used to create incentives to improve the environment.

The economic order quantity (EOQ) inventory model was first developed by Harris in 1913, which consists of ordering costs and holding costs. This model was later extended to economic production quantity model by Taff in the year 1918. These two models were modified by several researchers based on the needs of the production management with the incorporation of shortage, discount, price-break, switching, environmental conservation and other associated factors of business management. But in recent days the production sectors have begun to focus much on environmental sustainability. Bonney changed the stereotype in the development of inventory models by developing a paradigm shift towards environmental oriented inventory models comprising of social costs. These eco-friendly inventory models enhanced momentum and it laid a new platform for the researchers to explore eco-conscious inventory models. The environmental costing models were combined with inventory models to compute the carbon tax and other costs associated with environmental sustainable. Profit maximization inventory models also concentrate on disposal of waste were also developed. Environmental concerned inventory model focusing on waste mitigation was developed by Nivetha Martin and Ritha, in which the costs related to handle waste of different types (solid, liquid and gaseous) were discussed. But recently the need of battery waste management has motivated, to extend the enviro-eco conscious inventory model to combat battery-waste. Battery waste management inventory model has to be formulated as the generation of battery waste is increasing every year; also the rate of import of such waste is also getting accumulated. To handle such crisis an inventory model is formulated with the inclusion of all the possible battery waste management costs.

The rest of the paper is structured as follows: Section 2 explains the mathematical formulation of the proposed model. Section 3 illustrates a numerical example and Section 4 concludes the paper.

2. Mathematical Formulation:

To develop the proposed model, the following notations and assumptions are defined throughout this paper.

2.1 Notation:

D Demand per unit of time

P Production per unit of time

X D/P

1-X The fraction of time the production process spends actually idling

A Setup cost per production run

h Holding cost per unit of time

P_c Unit production cost

M_P Purchasing cost of machinery and electrical equipment

P_e Emission cost for production process

M_c Maintenance cost of Machinery

f_c Fixed cost per trip

v_c Variable cost per unit transported per distance travelled

d_t Distance travelled from manufacturer to supplier

α Proportion of waste returned ($0 \leq \alpha \leq 1$)

β Social cost from vehicle emission

a_v Average velocity

R_e Resource circulation cost

I_c Incentive for reuse of products

R_c Refund cost for returned products

G_p Environmental product taxation

B_{wc} Cost for collecting battery waste

B_{ds} Cost for disassemble and shred batteries

B_{Re} Cost for recover electrolyte

B_s Cost for separate cathode, anode and metals

B_R Cost for recycling battery waste

2.2 Assumptions:

1. Production rate and demand rate are constant($P > D$).
2. The production quantity is produced in batches.
3. Shortages are not allowed.
4. Deposit-refund system uses to achieve return and safe disposal of batteries.
5. Battery waste management focuses on waste reduction, pollution prevention, recycle and disposal.

2.3 Mathematical Model:

Consider a manufacturing company that produces at a constant rate to satisfy its deterministic type of demand. The production process takes place continuously and meets the needs of customers. The deposit system is used to change consumer behaviour by incentivizing the return of product or end-of-life products. In general, the law establishing the DRS mandates will help the manufacturers and retailers take specific actions or to govern the collection and disposal of returned products. And also Non-biodegradable battery waste is disposed of properly.

EPQ cost per unit of time = $\frac{AD}{Q} + \frac{hQ(1-x)}{2}$

Production cost per cycle = $P_c D$

Purchasing cost of Machinery = $\frac{D}{Q} M_p$

Maintenance cost of Machinery = $\frac{D}{Q} M_c$

Emission cost for production process = $\frac{D}{Q} P_e$

Transportation cost = $\frac{D}{Q}(2f_c) + D\big(v_c d_t(1+\alpha)\big)$

Emission cost for transportation process = $\frac{D}{Q}\left(\frac{2\beta d_t}{a_v}\right)$

Resource circulation cost = $\frac{D}{Q} R_e$

Incentive for reuse of products = $\frac{D}{Q} I_c$

Refund cost for returned products = $\frac{D}{Q} R_c$

Environmental product taxation = $\frac{D}{Q} G_p$

The associated battery waste management costs per cycle = $\frac{D}{Q}(B_{wc} + B_{ds} + B_{Re} + B_s + B_R)$

Total cost per unit of time

$$TC(Q) = \frac{AD}{Q} + \frac{hQ(1-x)}{2} + P_c D + \frac{D}{Q} M_p + \frac{D}{Q} M_c + \frac{D}{Q}(2f_c) + D\left(v_c d_t (1+\alpha)\right) + \frac{D}{Q}\left(\frac{2\beta d_t}{a_v}\right) + \frac{D}{Q} P_e + \frac{D}{Q} R_e + \frac{D}{Q} R_c + \frac{D}{Q} G_p + \frac{D}{Q}(B_{wc} + B_{ds} + B_{Re} + B_s + B_R) - \frac{D}{Q} I_c$$

The objective is to determine the optimal order quantity. The necessary condition is

$$\frac{\partial TC(Q)}{\partial Q} = 0$$

The optimal order quantity Q^* is

$$Q^* = \sqrt{\frac{2D\left(A + M_p + M_c + 2f_c + \frac{2\beta d_t}{a_v} + P_e + R_e + R_c + G_p + B_{wc} + B_{ds} + B_{Re} + B_s + B_R - I_c\right)}{h(1-x)}}$$

3. Numerical Example:

Consider an inventory system with the following data.

D	10,000 units/year
P	15,000 units/year
A	\$ 100
h	\$ 1.5/unit/cycle
P_c	\$ 250
M_P	\$ 1000
f_c	\$ 20
v_c	\$ 4
d_t	150 km
α	0.1
β	\$ 15
a_v	50 km/h
P_e	\$ 12
M_c	\$ 55
R_e	\$ 40
I_c	\$ 60
R_c	\$ 25
G_p	\$ 15
B_{wc}	\$ 50
B_{ds}	\$ 40
B_{Re}	\$ 35
B_s	\$ 20
B_R	\$ 30

Using the above data, we obtain

The optimal order quantity is 7726 units.

The total cost for inventory is \$ 9,103,862.448

4. Conclusion:

A production quantity inventory model with a combination of battery waste management costs is proposed in this paper. Production and consumption practices must be reorganized towards sustainability. This research will also help local investors broaden their horizons into the lucrative waste battery recycling business. This will help local producers understand that they can save a lot by reusing waste, reducing the supply of raw materials as well as the energy required to process them. The result show that battery waste management decreases the environmental impact. Increased efforts should be made to improve existing practices such as collection systems and management practices to reduce illegal trade in waste batteries as well as to protect the environment and public health.

References:

1. Abdulhasan, M. J., Hanafiah, M. M., Nizam, N. U. M., Wajeeh, H. Z., Abdulaali, S. H. (2019). Profiling environmental awareness of local community on solid waste management in nasiriyah, Iraq, International Journal of Advanced Science and Technology, 28(15), pp. 48–62.
2. Anna Boyden, Vi Kie Soo, Mathew Doolan. (2016). The environmental impacts of recycling portable Lithium-Ion batteries, Elsevier, Procedia CIRP 48, pp. 188-193.
3. Barletta, I., Larborn , J., Mani , M. (2016). Towards an Assessment Methodology to Support Decision Making for Sustainable Electronic Waste Management Systems: Automatic Sorting Technology, sustainability, 8(24), pp. 1- 20.
4. Elena Mossali, Nicoletta Picone, Luca Gentilini, Olga Rodriguez, Juan Manuel Perez. (2020). Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments, Journal of Environmental Management, 264, 110500, https://doi.org/10.1016/j.jenvman.2020.110500.
5. Han, D., Chen, X. (2019). Environmental Cost Research Hotspots and Frontier Analysis-Visual Analysis Based on Cite space, IOP Conf. Series: Earth and Environmental Science, 332(2), pp. 1–8.
6. Kurz, L., Faryadras, M., Klugius, I., Reichert, F., Scheibe, A., Schmidt, M., Worner, R. (2021). Global warming potential of a new waterjet-based recycling process for cathode Materials of Lithium-ion batteries. Batteries 2021, 7, 29. https://doi.org/10.3390/batteries7020029.
7. Mahajana, B. V., Patilb , L., Kumar, S. P. (2015). A Review Paper on E-Waste Management, IOSR Journal of Mechanical and Civil Engineering, pp. 15-21.
8. Mmereki, D., Li, B., Hong, L. (2016). The Generation, Composition, Collection, Treatment and Disposal System, and Impact of E-Waste. INTECH, pp. 66-94.
9. Mukhopadhyay, A., Goswami, A. (2014). Economic Production Quantity Models For Imperfect Items With Pollution Costs, Systems Science & Control Engineering, 2(1), pp. 368–378.
10. Prazanova, A., Knap, V., Stroe, D.I. (2022). Recycling of Lithium-ion batteries from electric vehicles, Part I: Recycling Technology, Energies 2022, 15, 1086. https://doi.org/10.3390/en15031086.
11. Ritha, W., Nivetha Martin. (2013) Environmental oriented inventory Model and benefits of incineration as waste disposal method,

Aryabhata Journal of Mathematics and Informatics, 6(1), pp. 159–164.

12. Sarkar, B., Ahmed, W., Choi, S. B., Tayyab, M. (2018). Sustainable Inventory Management for Environmental Impact through Partial Backordering and Multi-Trade-Credit-Period, Sustainability, 10(12), pp. 1–28.
13. Sasireka, A., Nandhu Kishore, A. H., Femila Mercy Rani, J., and N. Martin. (2020). Inventory model to combat E-waste management costs, Advances in Mathematics: Scientific Journal, 9, No.5, pp. 3059-3065.
14. Taft, E.W. (1918). The most economical production lot, Iron Age, 101, pp. 1410–1412.
15. Toyohisa Fujita, Hao Chen, Kai-tuo-Wang, Chun-lin He, You-bin Wang, Gjergj Dodbiba. (2021). International Journal of Minerals, Metallurgy and Materials, Vol. 28, No. 2, pp. 179-192.
16. Wang, Y., An, N., Wen, L., Wang, L., Jiang, X., Hou, F., Yin, Y., Liang., J. (2020). Recent progress on the recycling technology of Li-ion batteries, Journal of Energy Chemistry, doi: https://doi.org/10.1016/j.jechem.2020.05.008.